

<b>TITLE</b>  <b>SPECIFICATION FOR ST-5 LI-ION BATTERY</b>	<b>DOCUMENT NUMBER</b>  <b>ST5-495-006</b>	<b>REVISION</b>  <b>INITIAL</b>	<b>TOTAL PAGES</b>  <b>24</b>
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## TECHNOLOGY DEVELOPMENT

### **NEW MILLENNIUM PROGRAM** **SPACE TECHNOLOGY 5 PROJECT** **NANOSAT CONSTELLATION TRAILBLAZER PROJECT (CODE 495)** **NATIONAL AERONAUTICS AND SPACE ADMINISTRATION** **GODDARD SPACE FLIGHT CENTER** **GREENBELT, MARYLAND**

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## 1.0 INTRODUCTION

This Specification defines the general requirements for rechargeable Space Flight batteries intended for use in the ST-5 program. The battery chemistry chosen for this mission is lithium ion (Li-Ion).

## 1.1 SCOPE

The contractor shall furnish personnel, service, parts, materials, equipment and facilities necessary to design, analyze, manufacture, inspect, test and deliver the space flight hardware in accordance with the requirements contained within this document.

## 1.2 DEFINITIONS

Throughout this document, the term "C", or fraction of this term (e.g. C/2), will be used to describe the current for either charging or discharging the battery. The term "C" is a current numerically equal to the manufacturer's rated capacity in ampere-hours. Therefore, to charge a manufacturer's cell or battery rated at 20 ampere-hours at C/2 would be to charge the cell or battery at a current of 10 amperes.

Throughout this specification, TBS implies information required by the supplier whereas TBD or TBR implies information to be supplied or updated by the NASA/GSFC. All TBS/TBD requirements shall be negotiated during the preliminary and detailed designs and agreed to prior to the start of fabrication and assembly.

## 1.3 ACRONYMS

Ah or Amp-hr.....	ampere-hour
ATP.....	Acceptance Test Procedure
BBR.....	Battery Buyoff Review
C.....	current equal to manufacturer's rated capacity
deg C.....	degrees Celsius
CBR.....	Cell Buyoff Review
C/D.....	charge/discharge
CCDR.....	Cell Critical Design Review
DOD.....	depth of discharge
DPA.....	Destructive Physical Analysis
EOC.....	end of charge
FMEA.....	Failure Mode Effects Analysis
GSFC.....	Goddard Space Flight Center
MCD.....	Manufacturing Control Document
MSR.....	Monthly Status Report
NASA.....	National Aeronautics and Space Administration
NDE.....	Non Destructive Evaluation
QA.....	Quality Assurance
Spec.....	Specification
ST-5.....	Space Technology 5
V/T.....	temperature-compensated voltage limit

## 1.4 APPLICABLE DOCUMENTS

## 1.5 DRAWINGS

TBS  
TBS

Li-Ion Battery Interface Control Drawing  
Li-Ion Battery Electrical Schematic

## 1.6 SPECIFICATIONS AND STANDARDS

The following documents provide information that is usually applicable to specific requirements for Space Flight batteries. However, in lieu of such specific requirements, the following documents may be used by the contractor as guidelines.

- Program Specific

ST5-495-010.....	Project Mission Assurance Requirements
ST5-495-007.....	Component Test Requirements and Guidelines

- Goddard Space Flight Center

PPL 21.....	GSFC Preferred Parts List
S-311M-70A.....	GSFC Specification: DPA of Electronic Parts
S-313-100.....	GSFC Fastener Integrity Requirements
311-INST-001.....	Instructions for EEE Parts Selection, Screening and Qualification

- NASA

NASA REF PUB 1124.....	Outgassing Data for Selecting Spacecraft Materials
NHB 5300.4 (3A-2).....	Requirements for Soldered Electrical Connections
NHB 5300.4 (3G).....	Requirements for Interconnecting Cables, Harness, and Wiring
NHB 5300.4 (3H).....	Requirements for Crimping and Wire Wrap
NHB 5300.4 (3J).....	Requirements for Conformal Coating and Staking of PWB

- Military Standards

MIL-STD-105.....	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-1522A.....	Standard General Requirements for Safe Design and Operation of Pressurized Missiles and Space Systems
MIL-STD-1595A.....	Aerospace Welder Performance Qualification (April 1963, Notice 1)
MIL-STD-45662.....	Calibration System Requirements

- Federal Standards

FED-STD-209B.....	Clean Room and Work Station Requirement, Controlled Environment
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- Other Guidelines

Q9001-1994.....	American National Standards Institute/American Society for Quality Control Standards
ASTM E 595.....	Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM) from Outgassing in a Vacuum Environment
EWR 127-1, 1997 revision.....	Range Safety Manual
MSFC-SPEC-522.....	Design Criteria for Controlling Stress Corrosion Cracking
MSFC-HDBK-1453.....	Fracture Control Program Requirements
MSFC-HDBK-505A.....	Structural Strength Program Requirements
MSFC-STD-1249.....	Standard NDE Guidelines and Requirements for Fracture Control Programs
ANSI/ASQC Q9001-1994.....	American National Standard: Model for Quality Assurance in Design, Development, Production, Installation, and Servicing

## **2.0 REQUIREMENTS**

### **2.1 ITEM DEFINITION**

The ST-5 Li-Ion Battery shall consist of two matched cells designed using Li-Ion chemistry and high tolerance separator technology to produce a stored energy capacity in a low volume, low weight package. The combination of chemical composition and high tolerance separator design shall achieve gravimetric and volumetric energy densities unachievable with current Li-Ion technology. The battery shall interface directly with the ST-5 Electrical Power Distribution Subsystem and shall provide sufficient telemetry to assess the health and safety of the battery during ground testing and on-orbit operations.

### **2.2 MECHANICAL INTERFACE**

#### **2.2.1 System Size, Volume and Mass**

The center of mass and dimension for the battery shall be identified on the Battery Interface Control Drawing. The mass, size and volume requirements shall be as specified in Table 2.

#### **2.2.2 Structure Mounting**

The location of mounting hardware for the battery shall be specified on the Battery Interface Control Drawing. The physical mounting technique, including surface, thermal and electrical requirements shall be as specified in Table 2.

#### **2.2.3 Harness Connections**

The contractor shall be responsible for all necessary Battery internal harnessing. The location and orientation of all connectors in addition to the routing of all internal harnessing shall be identified on the Battery Interface Control Drawing. The system internal and external harnessing and connection requirements shall be as specified in Table 2, including connector type and wire type requirements.

### **2.3 ELECTRICAL INTERFACE**

The Battery shall interface directly with the ST-5 Electrical Power and Distribution Subsystem (EPS).

#### **2.3.1 Telemetry and Command**

All telemetry from the battery shall be facilitated as an interface with the ST-5 EPS subsystem. The EPS subsystem shall then be responsible for interfacing with the ST-5 C&DH subsystem for transmission of information to the ground.

### **2.4 CHARACTERISTICS**

The battery shall meet all requirements of this specification over the design life and with the environments defined in section 2.5. Beginning of life (BOL) test limits shall be de-rated as necessary to meet the end of life (EOL) requirements defined below.



## 2.4.2 Cell and Battery Design and Construction

The Battery shall be designed in accordance with the stipulations presented in Table 2 and the following guidelines.

- (a) ESD mitigation..... Internal metallic items (part spot shields, heat sinks, etc) shall have < 1 Gohm (TBR) dc resistance to ground (i.e., no floating metal).
- (b) Magnetic Design..... Care shall be taken to minimize hard and soft magnetic material (<TBD grams.). Circuit layout and wire routing shall be designed to minimize static and dynamic magnetic signatures (<TBD amp-m<sup>2</sup>). Unit shall be test verified if margin determined by analysis (including effects of current loops) is insufficient.

**Table 2: Cell & Battery Design**

Battery Type.....	Contractor shall provide Lithium Ion cells that meet the requirements of this GSFC Specification.
Battery Rated Capacity .....	Contractor shall specify the ampere-hour size (C) of each battery based at 25 degrees C to meet the depth of discharge & number of charge/discharge cycles for this mission; also, contractor shall provide this data as well as capacity data at the temperature extremes of the mission.
Battery Mass .....	Contractor shall specify the battery mass including mass breakdown of cells & other battery components. Maximum battery mass shall not exceed 382g.
Battery Volume .....	Contractor shall specify the battery dimensions in all directions including a description of where clearances and access are required to accommodate electrical and mechanical integration to the battery. Battery volume shall not exceed 6.67x6.35x6.35 cm.
Battery Mounting .....	Contractor shall specify the battery mounting surface including the Interface material, finish, area, pattern, smoothness, and mounting holes.
Battery Structural.....	Contractor shall specify the battery structural design that meets all integrity design qualification levels for the launch environments as specified in section 2.11; also, contractor shall provide inputs to the GSFC structural analysis and shall perform tests to validate the GSFC model..
Battery Thermal.....	Contractor shall provide GSFC with inputs for the GSFC-generated thermal model. The contractor shall perform testing at various charge/discharge rates to validate this model.
Battery Electrical Power Interface .....	Contractor shall provide the electrical interface for flight power and shall indicate the type, quantity, & size of wiring, connectors, and grounding. The battery shall have suitable interfaces (connectors) for power, battery telemetry and for ground support. Contractor shall provide the electrical interfaces for individual cell monitoring. All monitoring circuits will be located on the spacecraft side and will be the responsibility of GSFC.
Battery Materials .....	Contractor shall provide a list of all battery materials and shall identify out-gassing levels and resistance to moisture/corrosion damage during ground operations, if known.
Battery Telemetry .....	Contractor shall install one temperature sensor per cell prior to battery assembly. The location of sensors shall be indicated on the Battery Interface Control Drawing.
The items in this table shall be specified by the contractor and submitted to GSFC for approval	

## 2.4.3 Cell and Battery Manufacturing

The Contractor shall provide all the necessary manufacturing resources to fabricate flight quality cells and batteries in accordance with this document. The contractor shall manufacture and deliver all hardware identified herein and listed in the contract schedule.

Cell fabrication shall meet the requirements of this document and shall be in accordance with the contractor-generated GSFC-reviewed and mutually agreed upon Cell Manufacturing Control Document. The Cell Manufacturing Control Document shall include a detailed plan for the cell fabrication and assembly flow, parts list, materials list, test procedures and customer inspection points.

Battery fabrication shall meet the requirements of this document and shall be in accordance with the contractor-generated GSFC-reviewed and mutually agreed upon Battery Manufacturing Control Document. The Battery Manufacturing Control Document shall include a detailed plan for the battery fabrication, assembly flow, parts list, materials list, test procedures and inspection points.

The Battery shall be designed to operate properly in accordance with the stipulations presented in Table 1, Table 3 and the following environmental requirements.

- (a) Radiation..... (See Table 3)
- (b) Thermal
- (i) Operating (deg C):.... (See Table 1)
- (ii) Transients:..... xx °C swing over a xx min duration (TBD)
- (iii) Life Cycles:..... (See Table 3)
- (a) Launch Loads (g's): 11; Each Axis
- (b) Pyroshock (in/sec): TBD
- (c) Transport Loads (g's): TBD

Orbit .....	200 km by 6.6*Re Altitude
Solar Orientation to vehicle spin axis .....	10.52 Hrs Period (in-sun=8.64 hr; eclipse=1.88 hr)
Mission Life.....	90 degrees +/- 25 degrees
Battery Operating Temperature:.....	> 3 months
Charge/Discharge Cycles.....	-10 degrees C to 40 degrees C
Flight:.....	400 cycles at depth of discharge 60% or shallower
Ground:.....	100 cycles at depth of discharge 100%
Discharge Load.....	< 11 Watts (TBR)
Discharge Duration.....	TBD Hours
Pre-Launch.....	TBD Hours
Ascent:.....	1.88 Hours maximum per orbit
Flight:.....	8.64 Hours or greater per cycle
Charge Duration.....	60% (or shallower if required to meet all performance requirements during the entire mission)
Depth of Discharge Limit During Mission .....	100krad
Radiation Tolerance .....Total Ionizing Dose (TID):.....	TBD MeV-cm^2/mg
Linear Energy Transfer (LET):....	

## 2.6 REPORTING

The contractor shall participate in status telephone conferences (telecons) as required to communicate progress and problems. This is an informal exchange of information and status. The content shall include a summary of the period's schedule progress, issues, problem areas, and activities on-going and planned. Other subject matter covered may include definition of technical interfaces and component characteristics. The contractor and GSFC Technical Officer (TO) may mutually decide that some combination of telecons and e-mail communication on a different time interval is a more efficient way to pass information and status. At a minimum, status shall be communicated to the TO monthly. Note that the GSFC Technical Officer (TO) may also be referred to as the Contracting Officer's Technical Representative (COTR). The GSFC Technical Officer and/or her/his designee shall have access to all unrestricted areas and facilities where work is being performed on this contract. Escorted access to the contractor's restricted work areas related to this contract shall be provided to GSFC. The contractor's point of contact shall be notified prior to escorted access into restricted areas.

## 2.7 REVIEWS AND DOCUMENTATION

### 2.7.1 Reviews/Meetings

The contractor shall conduct all reviews at his facility and provide schedule status and the noted data and responses. Reviews shall be on or before the dates established between the GSFC Technical Officer and the contractor's point of contact. A Review shall not be considered closed until all open action items have been completed.

#### 2.7.1.1 Cell Critical Design Review

A Cell Critical Design Review (CCDR) shall be conducted following cell and battery design, but prior to fabrication. The review shall provide GSFC with cell and battery design data and analysis to show an overall compliance with the battery requirements.

#### 2.7.1.2 Cell Buy-off Review

A Cell Buy-off Review (CBR) shall be conducted following cell fabrication and acceptance testing, but prior to start of battery build. Cell acceptance data and all other data contained within the Cell Test Data Package shall be presented to demonstrate to GSFC the adequacy of each cell lot.

#### 2.7.1.3 Battery Buy-Off Review

A Battery Buy-off Review (BBR) shall be conducted prior to battery delivery. Battery acceptance data and all other data contained within the Battery Data Book shall be presented to GSFC to demonstrate compliance with all requirements.

### 2.7.2 Documentation

The contractor shall generate and maintain all documentation required to manage the work effort, document the design and verify that the design and hardware are in accordance with contractual requirements. The Contractor shall maintain color photographs to document the work under this contract. The Contractor shall choose what to document, and this shall include physical cell characteristics, test setups, anomalies, repairs, and hardware status throughout the cell and battery assemblies and test phases. The contractor shall make these photographs available to GSFC upon request.

### 2.7.2.1 Cell Critical Design Data Package

The manufacturer shall provide to GSFC a cell critical design data package. The data package shall be delivered 15 days prior to the date of the review. This data package shall provide all cell and battery design and analysis which ensures the proposed design meets all the requirements in this document and is in sufficient detail for fabrication to begin. At a minimum, the design package shall include the following:

- Drawing package including: parts list, and design, assembly and interface drawings, process flow/travelers, customer inspection points
- Materials and Process List,
- Electrical interfaces,
- Battery Handling and Storage Plan,
- Qualification and Acceptance Test Plan/Procedure.

The following data items shall be furnished by GSFC, in coordination with the contractor, and included as part of the data package:

- Failure Modes Effects Analysis,
- Thermal analysis,
- Mechanical/Structural analysis.

### 2.7.2.2 Cell Test Data Package

Fifteen days prior to the Cell Buyoff Review, the contractor shall make available to GSFC a Cell Test Data Package. The data package shall contain cell fabrication and test data. (The Contractor is not required to furnish propriety information in hard copy form, but shall provide cell data (which may be transformed into relative characteristics) for review and concurrence at the plant by a GSFC battery engineer.) The package shall also include Signature Curve Analysis of the cells if the Contractor has performed this optional test (Refer to Appendix A for test description).

### 2.7.2.3 Meeting/Review Data Package

Following completion of a scheduled review/meeting as specified by section 2.7.1, the contractor shall produce a meeting/review data package for review and concurrence by GSFC. The data package shall include the following minimum information:

- Meeting Minutes as provided by contractor.
- Review Presentation material, to include all errata.
- Attendance List.
- Action Items, including closure date and responsibilities.
- Any verbal or written agreements.

### 2.7.2.4 Cell and Battery Manufacturing Control Document

A Manufacturing Control Document (MCD) shall be prepared upon completion of the cell and battery design. The MCD shall include all applicable specifications, drawings, flowcharts, inspection points, test specifications, and any other documentation to which the cells and batteries are built and tested. The contractor shall provide these documents to GSFC for review and concurrence. The MCD provided to GSFC may have proprietary information excluded, but must include a list of the proprietary information with all document numbers and revision numbers

### 2.7.2.5 Battery Data Book

A Battery Data Book shall be provided for each battery. The data book shall include all battery fabrication and test data and any other information necessary to ensure the battery meets the requirements of this document. The battery data book shall be presented to GSFC at the BBR. The data book shall include, as a minimum, the following:

- As-built configuration list.

- Open items list and reason for being open.

- As run test procedures with test results.

- Closed failure reports.

- A summary of all deviations and waivers applicable to deliverable items.

- Critical parameters trend data.

- Logbook including total operating time and cycle records.

- Battery fabrication and qualification/acceptance test data.

- Plate test data (if applicable) and cell fabrication and test data.

- Evidence of acceptance by contractor QA.

### 2.7.2.6 Cell and Battery Qualification and Acceptance Test Plan/Procedure

The manufacture shall produce a Qualification (QTP) and an Acceptance Test Plan/Procedure (ATP). The QTP and ATP shall be made available to the government for review and acceptance as part of the CCDR. The ATP shall be a subset of the QTP tests. QTP tests shall be conducted on a dedicated test article (Qualification unit) which is flight representative. ATP tests shall be conducted on all flight units.

### 2.7.2.7 Battery Shipping Handling and Storage Plan

The manufacturer shall prepare and provide for GSFC use a Battery Shipping Handling and Storage Plan. This plan shall provide the manufacturer's recommended procedures for all aspects of cell and battery handling to prevent performance degradation before flight. The plan shall include but not be limited to the following information:

- Transportation and storage handling, including charge state, battery configuration and temperature.

- Pre-launch and post-storage reconditioning procedures, including charge/discharge and rates and a timeline of events.

- Temperature, Discharge and charge rate limits.

- Undervoltage and overvoltage limits.

## 2.8 QUALITY ASSURANCE PROVISIONS

The Contractor shall implement a Quality Management System that complies with the spirit of ANSI/ASQC 9001-1994 and supply GSFC with their Quality Assurance Manual for review and concurrence. Third party certification/registration is not required. This system shall apply to all flight hardware, flight spares and critical GSE. It is recognized that some contractors currently maintain a Quality System that is not compliant with ISO 9001 Quality Requirements, but complies with the essence of ISO 9001. Because of the similarity of these quality systems, the contractor may request a deviation to meeting the full requirements of ANSI/ASQC9001-1994 for this contract only. Approval of the deviation shall be contingent on the contractor listing which of the 20 ISO elements (ANSI/ASQC 9001-1994 paras. 4.1 to 4.20) they are not compliant with along with a justification or plan for becoming compliant. GSFC shall be notified of any changes to the status of the QA program.

## 2.9 PARTS, MATERIALS AND PROCESSES

### 2.9.1 Product Changes

The GSFC shall be notified when the Contractor or the Contractor's suppliers propose changes to products, including: (a) changes in design, parts, materials, fabrication methods or processes, and (b) changes which may affect the quality or intended end use of the item. Any proposed changes shall require GSFC concurrence.

### 2.9.2 Parts and Materials Traceability

The contractor shall maintain traceability of parts and materials for the purpose of maintaining unique identification of the product throughout the procurement Receiving Inspection and Test System that is in compliance with 4.10.2 through 4.10.2.2 of ANSI/ASQC9001-1994.

### 2.9.3 Parts

All part, materials and processes shall be selected and screened. Parts, materials, contractor's screening process and processes lists shall be submitted to the government for review and concurrence as part of the MCD.

Electronic parts shall require radiation lot acceptance testing (RLAT) unless the radiation design margin (RDM) against the calculated exposure based on part test data (from 3 vendor date codes) is greater than five or the RDM based on generic test data exceeds 10. Radiation exposure levels shall be calculated with a ray trace method. Parts as shielded in the unit enclosure shall meet the predicted environment or equivalently parts should be shielded to one half the dose that the circuit can tolerate. All analyses shall be documented in and available for review and concurrence by the government and shall use appropriate part radiation de-ratings, shielding analysis and methodology.

### 2.9.4 Materials

In general materials shall be selected with a TML (Total Mass Loss) of  $< 1.0\%$  and a CVCM (collected volatile condensable material)  $< 0.1\%$ . Proposed materials and processes shall be reviewed and mutually agreed upon with the GSFC Materials Consultant. A list of these materials shall be provided to GSFC within 1 month of contract award. The developer shall maintain lists of these items (inorganics, metallics, polymeric, lubricants, and processes) and appropriate usage records.

Disclosure of proprietary materials and processes are not required. However, proprietary materials and processes shall be available for review and concurrence at contractor's and subcontractor's site. All noncompliant materials shall require the submission of a Materials Usage Agreement (MUA) to the GSFC for approval.

## 2.10 WORKMANSHIP

All parts and assemblies shall be designed, constructed and finished in a quality manner intended to produce defect free equipment. Particular attention shall be given to critical operations such as handling of items sensitive to ESD, cleanliness and contamination controls, electronic soldering and assembly, connector crimping and harness assembly, test and inspection and other pertinent manufacturing controls. The unit shall be free of sharp edges or corners which may cut or abrade thermal blankets. Workmanship shall be per MIL-STD-454 (TBD).

### 2.10.1 Fastener Certification

The Contractor shall comply with S-313-100, Goddard Space Flight Center Fastener Integrity Requirements for structural fasteners. Traceability shall be maintained for every fastener lot.

### 2.10.2 Fabrication Requirements

The following commercial or NASA workmanship standards may be used as guidelines for the work under this contract. Best commercial practices or equivalent standards used by the contractor are acceptable and may be review and concurrence by GSFC Quality Assurance:

Soldering of electrical connections:	NHB5300.4 (3A-2)
Cable, harness, and wiring interconnections:	NHB 5300.4(3G)
Crimping:	NHB5300.4(3H)
Conformal coating and staking:	NHB 5300.4(3J)
Printed wiring board design:	IPC-D-275
	[NASA alternative-NHB 5300.4 (3K)]
ESD control:	EIA-625
	[NASA alternative-NHB 5300.4 (3L)]

The developer shall provide printed wiring board coupons to GSFC, or to a GSFC approved laboratory for evaluation (TBD). Approval shall be obtained prior to population of printed wiring boards (TBD).

## 2.11 TESTING

The testing program for the Battery shall be designed according to the following requirements:

- (a) Initial (pre-environment) and Final (post-environment) Performance Tests (to include mission specific cycling, temperature range, rates, DOD, etc.) shall be conducted to establish data for trending comparison. Unexpected non-repeatability across environments shall be treated as a failure. Performance testing to the extent practicable shall also be conducted during thermal cycling to verify critical performance compliance over the Acceptance temperature range. During all environments the unit shall be powered and perceptive parameters shall be continuously monitored for failures or intermittent operation. General test guidelines shall be per MIL-STD - 1540C and/or MIL-STD-810 (TBD). Note that Qualification Testing shall be performed on the Protoflight or Qualification unit while Acceptance Testing shall be done on the Flight Units.
- (b) Connector savers shall be used for all testing to minimize mate/de-mate of the flight connector.
- (c) Test Tolerances are as follows:

**Table 4: Environmental Test Tolerances**

Condition	Tolerance
Temperature	± 3 °C
Pressure	
Above 1 Torr	± 10%
0.01 Torr to 1 Torr	± 25%
Below 0.001 Torr	± 80%
Relative Humidity	± 5%
Acoustic Vibration - Sound Pressure Levels	
1/3-Octave Band	± 3.0 dB
Overall SPL	± 1.5 dB
Vibration Frequency (Hz)	± 2%
Random Vibration Acceleration	
Power Spectral Density (G <sup>2</sup> /Hz)	
20 to 500 Hz (25 Hz or narrower)	± 1.5 dB
500 to 2000 Hz (50 Hz or narrower)	± 3.0 dB
Random overall GRMS	± 1.5 dB
Shock Response (Q=10)	
1/6 Octave band center frequency amplitude (G's)	± 6 dB with 30% of the response spectrum
0-2000 Hz	center frequency amplitude greater than
	nominal test specifications
>2000Hz	+ 10 dB/-6dB
Static Load	± 5%
Acceleration (static)	+/- 10%
Sinusoidal Vibration Amplitude	+/- 10%
Test Duration	10%

(d) Test Levels are as follows:

**Table 5: Environmental Test Levels**

	Acceptance (Flight Units)	Protoflight (Qualification Unit)
Pyroshock	<i>Not Required</i>	MPE +3 dB 2 shocks/axis; 3 axes
Random Vibration	MPE Flight Duration <sup>#</sup> /axis; 3 axes	MPE Flight Duration <sup>#</sup> /axis; 3 axes
Sinusoidal Vibration	<i>Not Required</i>	MPE Flight Duration <sup>#</sup> /axis; 3 axes
Structural Loads	<i>Not Required</i>	1.25 x flight loads
Thermal-Vacuum Cycle	MPE ± 10 °C; 8 cycles	MPE ± 10 °C; 4 cycles 1 x 10 <sup>-4</sup> Torr
Pressure	Proof test (1.5 x MEOP) Leakage Test (MEOP)	Proof test (1.5 x MEOP) Leakage Test (MEOP)
Burn-In	200 hrs total failure free on-time	200 hrs total failure free on-time
EMI/EMC/Magnetics	As Specified	As Specified

(MPE) Mission Predicted Environment see section 3.5

(\*) Test not required for protoflight if addressed by random vibration levels

(#) Flight duration or minimum of one minute

### 2.11.1 Pyroshock

- Qualification unit shall be tested per the maxi-max Shock response spectra (Q=10).
- Two shock exposures in each of 3 axes shall be applied.

### 2.11.2 Random Vibration

- (a) Random vibration levels are Gaussian with peak G's limited to  $3\sigma$  with tolerances.
- (b) Unit shall be un-powered during the test.
- (c) Qualification unit shall be instrumented to verify the unit's fundamental frequencies (first modes only).
- (d) The following test profile shall be used for both the qualification and flight units as appropriate.

**Table 6: Random Vibration Test Profile**

Frequency (Hz)	ASD Level ( $G^2/Hz$ )	
	Protoflight (Qualification)	Acceptance (Flight)
20	0.026	0.013
20-50	+6 dB/Oct	+6 dB/Oct
50-800	0.16	0.08
800-2000	-6dB/Oct	-6 dB/Oct
2000	0.026	0.013
Overall	14.1 Grms	10.0 Grms

### 2.11.3 Sinusoidal Vibration

- (a) Sinusoidal Vibration shall only be necessary if both FEM analysis and Random vibration testing show response at frequencies below 60 Hz.

### 2.11.4 Thermal Vacuum Cycling and Thermal Cycling

- (a) Perceptive parameters shall be monitored continuously throughout the test during all temperature and pressure transitions. Critical performance or functional tests shall be conducted at the temp extremes (after sufficient soak time to ensure internal equilibrium) and at the initial and final ambient temps while varying pertinent interface parameters (bus voltage, command logic levels, etc) and while operating in all possible modes. Critical temps should be monitored throughout the test and alarmed if possible.
- (b) The unit shall be mounted in a flight like manner for Thermal-Vacuum testing.
- (c) Unit average baseplate temperature shall be used as the temperature reference for all tests.
- (d) Unit (powered or unpowered ) shall not fail or suffer permanent degradation at the survival temp limits. Each unit shall undergo a minimum of one cycle to survival temp limits (minimum dwell time of 1 hr).
- (e) Unit shall be capable of turn on as well as meet full performance over the qualification temperature range. Each unit shall undergo a minimum of two hot and cold turn on demonstrations at the applicable temperature extremes.
- (f) Average temperature transition rate shall be  $> 1^\circ\text{C/minute}$ , each transition.
- (g) A four hour dwell (minimum) after temp stabilization to  $< 3^\circ\text{C/hr}$  at each temperature extreme shall be established for each cycle.
- (h) Performance and functional tests shall be exercised at temperature extremes of the first and last cycles. Mission specific information for the battery testing (rates, temperature extremes, DOD, cycles, etc) are contained in Tables 1 and 3.

- (i) At the survival limits, the unit shall be turned off, then cold started after a soak period sufficient to ensure unit internal temperature has stabilized then the unit shall be turn off, then hot start after electrical components have discharged.

#### 2.11.5 Pressure

- (a) Nominal vacuum pressure for testing is  $1 \times 10^{-5}$  Torr.

#### 2.11.6 Range Safety

- (a) The battery design must meet the requirements of the range safety document, EWR 127-1. Safety testing shall be done by the contractor at the contractor's facility.

#### 2.10.7 EMI/EMC/Magnetics

TBD

### 2.12 QUALIFICATION

#### 2.12.1 Cell Qualification

Cell qualification shall meet the requirements of this document. Cell qualification by similarity with a previously flight-qualified cell of the same capacity and design is acceptable. However, the contractor must provide proof through cell life test and flight experience that an existing cell design of the same capacity, which has been fabricated under an existing MCD and has been flight qualified to specifications which envelope the requirements specified within this document. In the absence of previous qualification data, cell qualification testing shall be required and the appropriate testing program provided in the Qualification and Acceptance Test Plan/Procedure.

#### 2.12.2 Battery Qualification

Battery qualification shall meet the requirements of this document. Battery qualification by similarity with a previously flight-qualified cell is acceptable. However, the contractor must provide proof through cell life test and flight experience that an existing cell design, which has been fabricated under an existing MCD has been flight qualified to specifications which envelope the requirements specified within this document. In the absence of previous qualification data, battery qualification testing shall be required and the appropriate testing program provided in the Qualification and Acceptance Test Plan/Procedure.

#### 2.12.3 Cell Acceptance Testing

Cell acceptance testing shall meet the requirements of this document and shall be detailed in the Qualification and Acceptance Test Plan/Procedure.

#### 2.12.4 Battery Acceptance Testing

The contractor shall perform the testing required by this document and shall be documented in the Qualification and Acceptance Test Plan/Procedure. Testing shall be performed to verify that all the requirements are met. The minimum required battery acceptance testing shall be as specified in Table 7. The battery shall continue to meet performance and mission requirements during and after exposure to the launch and operational environments specified in this document. The contractor shall provide all data measurements taken at convenient intervals during the battery acceptance tests.

**Table 7: Battery Acceptance Test Procedure****Physical Measurements**

The contractor shall measure the mass of the battery to the nearest gram and the center of mass of the battery to within a tolerance of  $\pm 0.25$  cm.

**Visual Inspection**

The contractor shall visually inspect the battery to verify that the battery complies with all design specifications and has no visual defects.

**Functional Testing**

Electrolyte Leak Check:.....No cell or battery shall exhibit electrolyte leakage  
 Isolation Resistance Check:.....100 Mohms or greater at 100 V DC  
 Temperature Sensor Checkout:.....Maintain calibration & specifications over temperature range  
 Room Temperature Capacity Test:.....1.0\*C or greater (@ 25 deg C)  
 Charge Retention Test:.....0.98\*C or greater after open circuit for 72 hours (@ 25 deg C)  
 Peak Load Test:.....6.0 V or greater after C/2 discharge for 1 hour plus 2\*C discharge for 5 minutes

**Launch Environment (Battery on Discharge)**

Static Load (may not be required for follow-on units)  
 Random Vibration  
 Sine Vibration

**Visual Inspection****Functional Testing****Flight Thermal Vacuum Environment**

Soak at + 50 degrees C and at -45 degrees C for the Qual battery, -15 deg C for the Flight batteries for a minimum of 4 hours  
 Electrical Performance/Mission Profile Cycles at + 25 degrees C: Contractor-specified/GSFC-approved  
 Electrical Performance/Mission Profile Cycles at -10 degrees C: Contractor-specified/GSFC-approved  
 Electrical Performance/Mission Profile Cycles at +40 degrees C: Contractor-specified/GSFC-approved

**Capacity Measurements (in the following sequence)**

Capacity Test.....@25 degrees C:.....1.00\*C or greater  
 .....@-10 degrees C:.....0.80\*C or greater  
 .....@40 degrees C:.....1.05\*C or greater  
 .....@25 degrees C:.....1.00\*C or greater

**Visual Inspection**

**Functional Testing** (GSFC will provide mission specific information for testing: rates, DOD, temperature range, cycles, as described in Tables 1 and 3).

**2.13 CONTROL, REPORTING AND DISPOSITION****2.13.1 Contamination Control**

The quality assurance personnel shall ensure that the requirements for cleanliness and contamination control are being complied with during all phases of the program.

### 2.13.2 Non-Conformance Control

The Contractor shall operate a closed-loop nonconformance control system for failures and discrepancies compliant with ANSI/ASQCQ9001-1994. The Contractor shall identify each nonconformance in a Material Review Board (MRB) as minor or major. A major nonconformance is defined as affecting reliability, workmanship, performance, safety, interfaces, or other approved GSFC documentation. Minor non-conformances are superficial or cosmetic flaws. All major non-conformances shall be submitted to the GSFC Quality Assurance Representative for approval. MRB's involving minor non-conformances may be dispositioned and approved by the contractor. Minor MRB's shall be documented and provided to the GSFC Technical Officer within 48 hours of disposition.

### 2.13.3 Failure Reporting

A failure report shall be immediately written for any departure from design, performance, testing, or handling requirements that affect the function of the flight segment or flight support equipment or could possibly compromise mission objectives. The Technical Officer shall be notified verbally and/or by email within 24 hours of the malfunction. Written notification in the form of a GSFC Problem/Failure Report (P/FR) or contractor equivalent form shall be made within 48 hours. Routine submission of formal P/FR shall begin with the start of performance testing of the component at the box level and it shall continue through formal acceptance by the GSFC project office.

Other problems or anomalies that are unusual or that might affect other areas of the spacecraft shall also be cited on a P/FR. Failures that occur prior to box-level acceptance testing shall be reported at the next status review. GSFC retains the option to require that a formal P/FR be submitted on a case by case basis for any failures reported at this level.

## 2.14 HANDLING, STORAGE, PRESERVATION, MARKING, LABELING, PACKAGING & SHIPPING

Products shall be stored, preserved, marked, labeled, packaged, and packed to prevent loss of marking, deterioration, contamination, or damage during all phases of the program. Stored and stocked items shall be controlled in accordance with documented procedures and be subject to quality surveillance.

### 2.14.1 Handling and Shipping

The contractor shall be responsible for the protection of the deliverable items during handling, transporting and delivery. The contractor shall provide all materials and personnel required to design, fabricate, and test the necessary handling fixtures, shipping containers, packaging material, and labeling to protect the completed cells and batteries against contamination, excessive condensation and moisture, and damage during handling, transportation, and delivery. The shipping containers shall include shock, temperature, and humidity recorders and shall be capable of accommodating cold packs for prolonged shipping conditions, if necessary. GSFC will work with the contractor to devise a mutually agreeable plan for selecting and mounting the shock recorders. A reliable method will be devised to monitor shock, while reducing the potential for false readings. These indicators may be furnished to the contractor by GSFC. The contractor shall be responsible for obtaining all documents and approvals for shipping batteries to the GSFC in accordance with this document.

Prior to shipping, quality assurance personnel shall ensure that:

- (a) Fabrication, inspection, and test operations have been completed and accepted.
- (b) All products are identified and marked in accordance with requirements. Shipping containers carrying flight hardware are clearly labeled as such.
- (c) The accompanying documentation (contractor's shipping and property accountable form) has been reviewed for completeness, identification, and quality approvals.

- (d) Packaging and marking of products, as a minimum, comply with Interstate Commerce Commission rules and regulations and are adequate to ensure safe arrival and ready identification at their destinations.
- (e) The loading and transporting methods are in compliance with those designated in the shipping documents.
- (f) Integrity seals are on shipping containers.
- (g) Special handling instructions for receiving activities are provided where appropriate, including proper labeling of containers and related documents to provide evidence of this verification. The contractor may use "best commercial practices" for packaging and shipping and has responsibility for any damage incurred during shipment.

## 2.15 GOVERNMENT ACCEPTANCE

Prior to acceptance by GSFC, quality assurance personnel shall ensure that deliverable end-items, including the Battery Data Book containing the verification data, are in accordance with development plan or contract requirements. A copy of the data package shall be submitted to GSFC in accordance with the contract and a copy shall accompany each end-item.

Final acceptance of the units shall be performed by the GSFC technical representative at GSFC and shall be based on an inspection of each unit for any shipping damage. The units will be conditionally accepted at the contractor's facility following the successful completion of the acceptance tests and the Battery Buyoff Review including the satisfactory closeout of all open items.

## 2.16 REQUIREMENT COMPLIANCE VERIFICATION

Compliance with all requirements of this document shall be verified. Methods of verification are: verification by analysis, verification by inspection, verification by test, and verification by demonstration. The manufacturer shall provide a verification matrix defining the method of verification for each specific requirement of this document.

## 2.17 UNIT CHARACTERIZATION

**Engineering Development Unit:** Designated as (E) and represents a non-flight functional and performance version of the final flight unit.

**Qualification Unit:** Designated as (Q) and represents a full flight unit that is tested to protoflight levels.

**Acceptance Unit:** Designated as (A) and represents a full flight unit that is tested to acceptance levels.

## 2.18 VERIFICATION LEVEL

**Inspection:** Designated as (I) and represents inspection of the physical hardware by a customer appointed qualified inspector for compliance.

**Analysis:** Designated as (A) and represents documentation of performance or function through detailed analysis using all applicable tools and techniques.

**Demonstration:** Designated as (D) and represents a demonstration of performance and/or functionality through a properly configured demonstration setup where all critical data of the demonstration is captured for review using standard inputs and outputs to the unit.

**Test:** Designated as (T) and represents a detailed test of performance and/or functionality throughout a properly configured test setup where all critical data taken during the test period is captured for review.

**2.19 VERIFICATION MATRIX**

The following matrix identifies each of the functional and performance requirements specified within this document and identifies how the requirement will be satisfied (i.e., the Level) and in what assembly the requirement will be specified (i.e., the Unit). The entire matrix shall be completed and negotiated with the supplier during Phase B and agreed to prior to the start of Phase C/D/E.

PARAGRAPH #	REQUIREMENT TITLE	LEVEL				UNIT		
		I	A	D	T	E	Q	A

**APPENDIX A: SIGNATURE CURVE ANALYSIS OF THE LITHIUM ION CELLS**

This test is not required under this contract, but it is included in case the Contractor chooses to perform the test.

A signature curve is a simple method of evaluating the rate performance of Lithium Ion cells. Originally developed by Jean-Marie Tarascon of Bellcore, it determines the rate performance at fractional C rates, typically from C/1 down to C/16, within the expanse of one discharge cycle. It is a fast and reliable method useful for evaluating cells based on rate performance and capacity.

A signature curve test starts with cells that are completely charged. This is important as it sets a common starting baseline. A summary of the method is shown below:

- (a) Start with a fully charged cell.
  - (j) Discharge at C/1 rate to 3.0 V.
  - (k) Rest for 15 minutes at open circuit.
  - (l) Discharge at C/1.5 rate to 3.0 V.
  - (m) Rest for 15 minutes at open circuit.
  - (n) Discharge at C/2 rate to 3.0 V.
  - (o) Rest for 15 minutes at open circuit.
  - (p) Discharge at C/4 rate to 3.0 V.
  - (q) Rest for 15 minutes at open circuit.
  - (r) Discharge at C/8 rate to 3.0 V.
  - (s) Rest for 15 minutes at open circuit.
  - (t) Discharge at C/16 rate to 3.0 V.
  - (u) End

The first discharge to 3.0 V at the C rate is simply the amount of capacity the cell delivers at the C rate. Because of concentration polarization in the electrodes, the cell voltage quickly recovers to about 3.6 volts and then stabilizes. Then the cell is discharged at the C/1.5 rate until the cell voltage again reaches 3.0 V, which it will do in a short time. The mA-hrs delivered at the C/1.5 rate plus the mA-hrs delivered at the C rate is the equivalent of discharging the cell at the C/1.5 rate. The voltage will recover again, but not as high as before. This is repeated for discharge at each rate, with a fifteen-minute open circuit rest between discharges. Since each rate is smaller than the previous, the total amount of mA-hrs discharged for all discharges is the equivalent of discharging the cell at the last rate only.